

***AERODYNE RESEARCH, Inc.***

**CAPS PM<sub>ssa</sub> Monitor**

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## TABLE OF CONTENTS

OVERVIEW	.....	5
1. OPERATING PRINCIPLES	.....	7
2. GETTING STARTED	.....	10
3. AUTOMATED BASELINE	.....	12
4. SCATTERING CALIBRATION PROCEDURE	.....	13
5. TRUNCATION	.....	14
6. DATA OUTPUT	.....	16
7. MAINTENANCE	.....	18
Particle Filter Replacement	..... 18	
Mirror Contamination	..... 18	
Cell Maintenance	..... 19	
8. SOFTWARE COMMANDS	.....	21
9. WRITING YOUR OWN DAQ	.....	24

**Unit Chassis is grounded through the 3-prong wall plug. However, in situations where the power supply is questionable, we recommend using a second ground wire attached to the screw on the lower right hand side**

## OVERVIEW

### MEASUREMENT SPECIFICATIONS

Measurement Range:	0-1000 Mm <sup>-1</sup>
Resolution:	0.1 Mm <sup>-1</sup>
Precision (2σ, 1s):	< 3 Mm <sup>-1</sup> (both scattering and extinction channels)
Time Response:	< 2 seconds
Baseline Drift:	automated baseline provided
Span Drift:	negligible

### PHYSICAL SPECIFICATIONS

Sample Flow Rate:	0.85 liters per minute
Purge Flow:	Provided internally
Cell Pressure:	ambient
Cell Temperature:	~5° above ambient
Power Usage:	< 40 Watts (@120 VAC)
Weight:	16 kg
Size:	~65 cm x 43 cm x 23 cm (L x W x H) mounting ears provided [19" rack mount, 5U, 24" deep]

### OPERATING CONDITIONS

Temperature:	5-35 °C
Relative Humidity:	0-90%

### INSTRUMENT CONTROL

1. No external controls on monitor
2. All instrument operating parameters adjustable using software interface using RS-232 connection

### DATA OUTPUT

Display	Front Panel, 1 second time constant (± 1 digit)
RS-232	Rear Panel, DB-9 Female Connector – <b>null modem cable required</b> 1 sample per second or slower (no handshake allowed)
USB	Rear Panel, Female B Connector (Male A to Male B cable provided)
Ethernet	Rear Panel, RJ-45 port
On-Board	>25 GBytes Storage Capacity

### SAMPLE HANDLING (on back panel)

Inlet	Stainless Steel, ¼" Swagelok™ connection on back panel
Exhaust	Brass ¼" Swagelok™ connection on back panel

## NOTES:

1. The monitor will correctly operate at ambient pressures down to ~300 Torr. If operated at pressures below ambient, performance degradation can be caused by mirror contamination. This will occur when the vacuum is released. If a substantial vacuum is encountered, attempt to release that vacuum very slowly to avoid particle upset.
2. For samples with high particle loadings (such as diesel engine exhaust), the user should check the pressure drop that occurs during a baseline measurement period. If the pressure drops by more than 20 Torr, the filter should be replaced.
3. Monitor Battery – The on-board computer that operates the monitor contains two AAAA batteries that allows the computer to retain the proper date and time. If this functionality is lost, the two batteries can be readily replaced. The data acquisition program will automatically time synchronize the monitor with the acquisition computer at ~ 12 A.M. each day.
4. If extinction levels above  $1000 \text{ Mm}^{-1}$  are regularly encountered, it is recommended that the sample flow be diluted with particle-free air to avoid both frequent changing of the filter elements and possible mirror contamination.
5. The scattering channel may show some non-linearity with respect to the measured extinction above extinction readings of  $1000 \text{ Mm}^{-1}$ . If accurate SSA measurements are required for extinction levels above  $1000 \text{ Mm}^{-1}$ , a separate calibration curve for these measurements must be recorded.

## SHIPPING MONITORS

**When units are shipped into the field, run dry air through the monitor for several hours and then plug inlet and outlet ports with Swagelock plugs. This helps to prevent mirror contamination during shipping.**

# 1. OPERATING PRINCIPLES

## Extinction

The Cavity Attenuated Phase Shift single scattering albedo (CAPS  $PM_{2.5}$ ) monitor as deployed here operates in one measurement channel as an optical extinction spectrometer, utilizing a visible light-emitting diode (LED) as a light source, a sample cell incorporating two high reflectivity mirrors centered at the wavelength of the LED and a vacuum photodiode detector. Its efficacy is based on the fact that aerosols are broadband scatterers and absorbers of light.

Unlike a conventional absorption spectrometer, in which the concentration of the absorbing species is determined by measuring the attenuation of light, the CAPS monitor relies on measuring the average time spent by the light within the sample cell. The presence of particles causes this average time to decrease as the particle concentration increases because of the propensity of particles to scatter or absorb light. Of course, given the high velocity of light (0.3 m per nanosecond) and the very low concentrations of particles typically found in the ambient environment, a very long path length within the sample cell is required in order to accurately measure this change in time. This is accomplished by forming the ends of the sample cell with high reflectivity mirrors ( $R \geq 0.9998$ ), a configuration which provides an optical path length on the order of 1-2 kilometers. In the absence of particles, the photon lifetime within the cell is on the order of several microseconds, a magnitude which is readily measured with high accuracy.

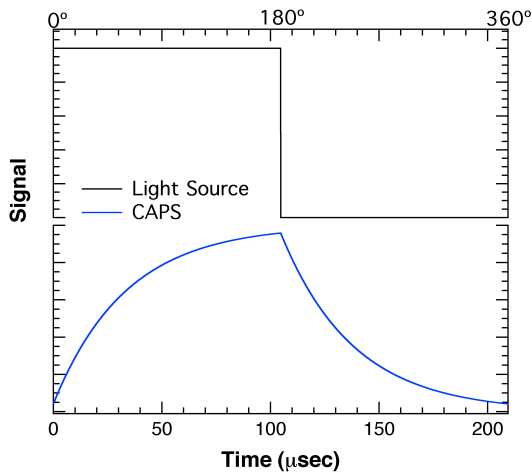


Figure 1. Waveforms of LED (top) and signal at detector (bottom)

In CAPS-based instruments, in order to measure the average time spent by the light within the sample cell, the LED output is square wave modulated and directed into the back of the first reflective mirror. The light beam passes through the absorption cell, out of the back mirror and into a detector where it appears as a distorted waveform which is characterized by a phase shift with respect to the initial modulation. (See Figure 1.) This distortion is the result of an exponential decay of the light within the cell as it leaks out through the mirrors. The amount of that phase shift ( $\theta$ ) is a function of fixed instrument properties - cell length, mirror reflectivity, and modulation frequency – and of the presence of aerosols using the following relationship:

$$\cot\theta = \left(\frac{c}{2\pi f}\right)\varepsilon + \cot\theta_0$$

where  $\cot$  is the cotangent,  $c$  is the speed of light,  $f$  is the LED modulation frequency, and  $\varepsilon$  is the absolute extinction of light caused by the presence of aerosols. The term  $\cot\theta_0$  is obtained from a periodic baseline measurement (using particle-free air). Thus,

$$\varepsilon = \left(\frac{2\pi f}{c}\right)[\cot\theta - \cot\theta_0]$$

Note that this measurement provides an absolute value, requiring, in theory, no calibration – all the other quantities in the above expression are known. However, it should be noted that this value is averaged over the effective spectral output of the light reaching the detector, a function of the particular LED,

bandpass filter and mirror reflectivity. Moreover, the need to provide a purge region to prevent contamination of the mirrors introduces a geometry correction factor reflecting the fact that the measurement baselength is not the full length of the cell. This factor is determined using measurement of the cross sections of various sized PSL particles.

The configuration of the monitor is quite simple and is shown below in schematic form in Figure 2. The high reflectivity mirrors are directly attached to the ends of the sample cell, forming the optical cavity which provides for the concentration measurement. The LED, optical filter and appropriate focusing optics are attached directly to the sample cell. The light emanating from the cell is directed into a vacuum photodiode where the resultant signal is integrated, digitized and sent to a PC-104 format computer where all subsequent data processing takes place. The sample cell contains both pressure and temperature sensors which allow for both accurate correction because of transient changes in the air Rayleigh scattering. As noted later, the pressure reading is also used to check on the proper operation of the particle filter. The volumetric flow through the cell is limited by a critical orifice that is backed by a diaphragm pump. This same pump is also used to generate a particle-free purge flow that is routed to the mirrors to minimize contamination.

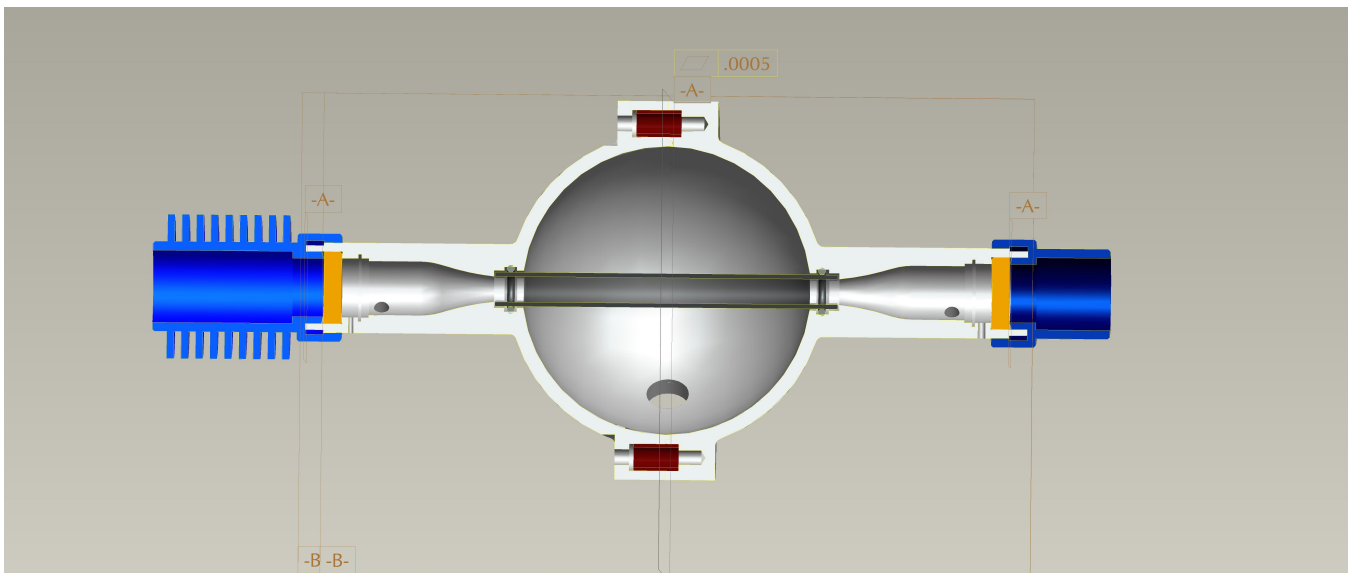


Fig. 2 Schematic of the PMssa monitor. The PMT module is located on an axis orthogonal to the plane of the drawing.

The integrating sphere is incorporated into the design of the monitor. The particle path within the sphere is constrained by a glass tube which preserves the flow path so as to preserve the time response and keep the sphere surfaces from becoming contaminated. Deposition of particles on the inside surface of the glass tube will slowly change the calibration. If that tube becomes highly contaminated, we recommend returning it to Aerodyne for servicing. The photomultiplier tube module attached to the sphere operates in a photon counting mode and is powered by 5V from the computer stack.

**DO NOT ATTEMPT TO UNBOLT THE SPHERE SECTION OF THE SAMPLING CELL.** It will not readily come apart.



## Scattering

In order to perform the scattering measurement, an integrating volume is incorporated into the extinction measurement cell. This integrating volume serves two purposes. The first is to maximize the collection of scattered light at the photomultiplier tube which views scattered light from the optical cell at right angles to the optical beam. The second is to minimize the light collection bias with respect to scattering angle. The white coating on the surface of the sphere not only has a broadband reflectivity of greater than 98%, but also provides a near perfect Lambertian surface – i.e., photons scatter at random angles which bear no relationship to the initial angle of incidence. Of course, the integrating volume is not perfect given that its reflectance is not 100% and there are finite openings in the volume to allow the optical beam to enter and exit. Thus, there is a truncation correction which is a function of particle diameter which must be considered. This will be discussed in detail in a later section.

The scattered light is detected by the PMT using single photon counting techniques with a suitable amplifier and discriminator, the output of which is sent to a separate digital counter. Note that there is no shield or baffle which prevents the PMT from viewing light which emanates from the light source and is scattered by the mirrors, optical apertures and various surfaces within the system back into the integrating volume. We are able to dispense with this requirement by electronically gating the signal accumulation counter so that it is operating only when the LED is off. This mode of operation is made possible by the fact that the use of a loss-loss cavity provides substantial optical circulating power within the cavity for microseconds after the LED is turned off. The only light within the cavity when the LED is off is highly collimated – i.e., reflecting back and forth between the mirrors – and thus minimizes unwanted scattering from the monitor surfaces. Of course, the amount of circulating power present in the cavity is a function of the optical loss within the cavity which must be accounted for when measuring the scattering, a task carried out by the monitor.

The output of the PMT is ratioed to the DC LED signal level measured by the vacuum photodiode used to detect extinction. Thus, the stability of the scattering channel calibration is sensitive to the drift in sensitivity of these two detectors. Currently, how the calibration changes with time is unknown and is probably dependent on the environment in which the monitor is used. **We recommend frequent calibrations (described below) until the user is confident as to their need.**

## 2. GETTING STARTED

1. Unpack shipping crate which contains the monitor, power cord, USB data cable, null modem RS-232 cable (9 pin) and laptop computer (all located under the monitor). There will also be a small bag containing lens tissue paper and two eye dropper bottles for cleaning mirrors, a 5/64" Allen wrench for taking off the top cover, a nut driver for loosening the clamps on the detector module and a spare particle filter. Off to one side will be aluminum ears which are using for rack mounting if desired.

### 2. REMOVE SWAGELOCK PLUGS ON INLET AND OUTLET PORTS ON BACK PANEL BEFORE POWERING UP.

3. Insert power cord into monitor AC/DC converter on back panel, plug into wall socket (100-240 VAC) and turn on power switch on back panel. AC/DC converter is a medical grade II power supply. All voltages within the monitor enclosure are 24 VDC or less. **The monitor takes ~30 s to boot up.**

4. The supplied laptop computer is already configured to operate our data acquisition software (referred to as **CAPS-DAQ** from hereon). CAPS-DAQ will automatically log the data and store it in a folder on the desktop. It also provides all commands necessary to set up the monitor. Connect the supplied USB cable to the monitor using the USB port on back panel and to the laptop computer. Start up the software and skip to instruction 5. You can also use a null modem cable to record data using a serial port if preferred. As of now, the ethernet streams real-time data and can also be accessed to download stored data files. You can also download a version of the CAPS-DAQ software and install it on your own Windows computer.

5. Within 30 seconds, data from the instrument should start appearing on the display panel on the front panel or in the display of the CAPS-DAQ software. If no data appears:

- a. Is the USB cable properly installed? If using the RS-232 port, is it a null modem cable?
- b. Is the port properly designated? (Most computers have multiple series and USB ports.)

If a connection is still not made, reboot host computer and look in the Device Manger of the Windows software. Use this designation in assigning the com port in CAPS software. If still not successful, try another serial/USB port and repeat process. You might also have to reboot the CAPS monitor as well.

6. The monitor is now ready for its initial setup. The default mode of the monitor is as follows:

Sample Period:	1 second
On-Board Time Stamp	Igor
Data Delimiter	comma

The sample period can be set to a number of integer values. It is recommended that sample periods longer than 30 seconds not be used for accurate results. If desired, data can be averaged post-measurement.

There are two different time stamps in the data files. The monitor provides its own internal time stamp (see CAPS-DAQ manual) that appears in the first column of data in the data file stored on the host data acquisition computer and also in the data file that is automatically stored on board

the monitor. The data acquisition software provides a second time stamp from the host computer when the data point is collected. The CAPS-DAQ software performs a clock synchronization with the monitor's internal clock when it first communicates with the instrument. It then resynchs the clock shortly after midnight so long as they remain connected.

A number of choices for the data delimiter are provided including comma (default), space, and tab.

7. Reset the baseline using a manual command if desired. See detailed instructions in Section 3.
8. Recalibrate scattering channel per instructions in Section

### 3. AUTOMATED BASELINE

The monitor is provided with an automated baseline capability. Under normal operation, the air/particle sample flows unimpeded into the measurement cell. Upon software command, a 3-way valve is switched so as to cause the sample flow to proceed through a filter which removes all particles. Upon the end of the baseline measurement, the valve returns to its normal position which bypasses the filter.

To use either the automated or manual baseline, the user must provide settings for proper operation of the valve using the supplied software. The two parameters that must be set are flush period and baseline period. The flush period refers to the amount of time required for the sample cell to be completely flushed out of any unfiltered sample; we recommend that this time be set to 15 seconds, which is approximately 8-10 cell flush lifetimes. The baseline period is the amount of time required to obtain an accurate baseline reading. We recommend setting this period to 60 seconds – longer baseline periods will not appreciably decrease and might even increase the noise associated with taking a baseline.

If automated baseline operation is required, the user must set the start time for operation and the period between baseline measurements as well. The start time is used to synchronize the baseline measurements with other instruments and can be set to any minute past the hour - the start hour is irrelevant. The period between baseline measurements can be set to any desired length; however, it is recommended that if the period is less than 1 hour, that it be divisible into 60 (i.e., 10, 12, 15, 20, 30 minutes).

The user should be aware that the longer the baseline/flush period and the shorter the interval between baselines the lower the duty factor or actual measurement time. For low particle extinction environments ( $<10 \text{ Mm}^{-1}$ ), it is recommended that if the flush and baseline periods are set to those noted above, the interval between baselines be set to 15 or 30 minutes for best precision. In this case, the duty cycle will be 90% or greater. For higher extinction environments, the interval can be lengthened appreciably.

**The instrument as a default condition comes with the automated baseline enabled.** This ensures that during ambient monitoring, in the event of a power failure, the instrument continues to operate properly when the instrument powers up upon resumption of electrical service. In laboratory service, the user should consider disabling the automated baseline option using the data acquisition software.

#### 4. SCATTERING CALIBRATION PROCEDURE

Although the instrument is shipped pre-calibrated at Aerodyne Research, it should be recalibrated upon receipt and periodically during use to ensure the highest degree of accuracy. The scattering channel is best calibrated using polystyrene latex particles (PSLs) or ammonium sulfate (or other non-absorbing salt) particles in the **size range of 100 to 300 nm**, a range of particle sizes for which the instrument displays no truncation error.

The recommended procedure involves aerosolizing an aqueous solution of PSLs (or salt) using air, drying the resultant particles using a diffusion or Nafion drier and using a differential mobility analyzer to size select the particles. (This last step minimizes contamination of the flow stream with large particle aggregates which could contribute to truncation errors.) The CAPS PM<sub>ss</sub> monitor should then be challenged with multiple concentrations of PSLs and the scattering channel reading recorded versus the measured extinction. Manual baselines should be activated between each level of PSL concentration to ensure maximum accuracy.

**When either taking a baseline or calibrating the instrument, wait at least 5 minutes after startup to allow monitor to reach final operating temperature.**

The scattering channel readings should then be plotted against the extinction channel readings as shown below in Figure 4. A linear least square fit to the data should be performed. The slope of this fit is the correction to the span value that must be entered into the appropriate place in the monitor software. Once this data has been stored and saved, the span constant of the monitor will reflect last calibration. Any long-term trends in the value of the span constant would indicate that there is either a systematic change in the monitor. We recommend that a listing of calibration constants as a function of time be kept to allow for discerning long term trends.

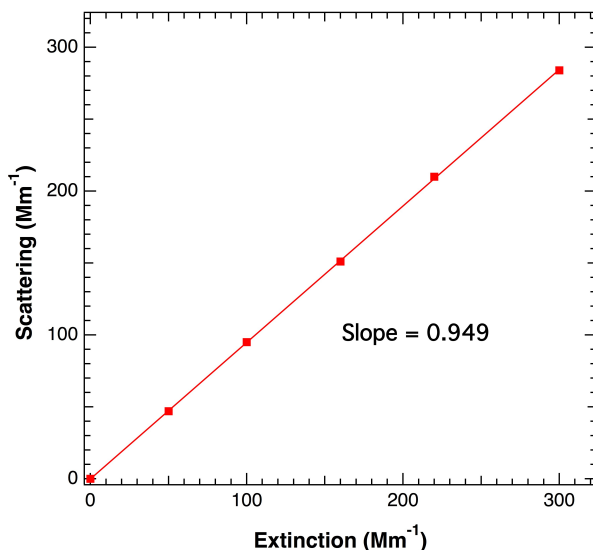


Fig. 4 Calibration plot of monitor scattering channel readings versus the measured extinction readings. The slope of the linear least squares fit to the data is also shown.

## 5. TRUNCATION CORRECTION

Particles that obey Mie scattering (i.e., spherical and uniform) demonstrate scattering phase functions (i.e., scattering angular distributions) which are a function of particle diameter. As particles become larger in diameter, the amount of scattering in both the forward and backward directions increases – i.e., scattering is NOT isotropic. As noted above, the integrating sphere has openings in the forward and backward directions to allow the entrance and exit of the light beam and thus does not collect some cone of light at  $0^\circ$  and  $180^\circ$ . The amount of light not collected by the integrating sphere thus increases as a function of particle size requiring a correction to the measured scattering.

We have measured this bias with respect to particle size carefully using PSLs (index of refraction =1.59) at both 450 nm (blue) and 630 nm (red) and reproduce the result below in Fig. 5. Note the effect of Mie resonances at  $\sim$ twice the interrogation wavelength which result in sudden reductions in the truncation effect. The figure also shows fits to these data using Mie scattering calculations and the geometry of our sample cell. The fits at both wavelengths are reasonably good, but not perfect, indicating that we still do not completely understand the results.

However, these results stand for only monodisperse particle size distributions. For ambient monitoring purposes or when measuring any polydisperse particle stream, this truncation curve must be averaged over the size distribution of the particle stream. We have provided a Windows-compatible program, **MieAmigo**, in 32-bit and 64-bit versions for this calculation. The user can assume a log-normal size distribution and enter a center particle size and geometric width of the distribution or enter a measured distribution as  $dN/dd$ .

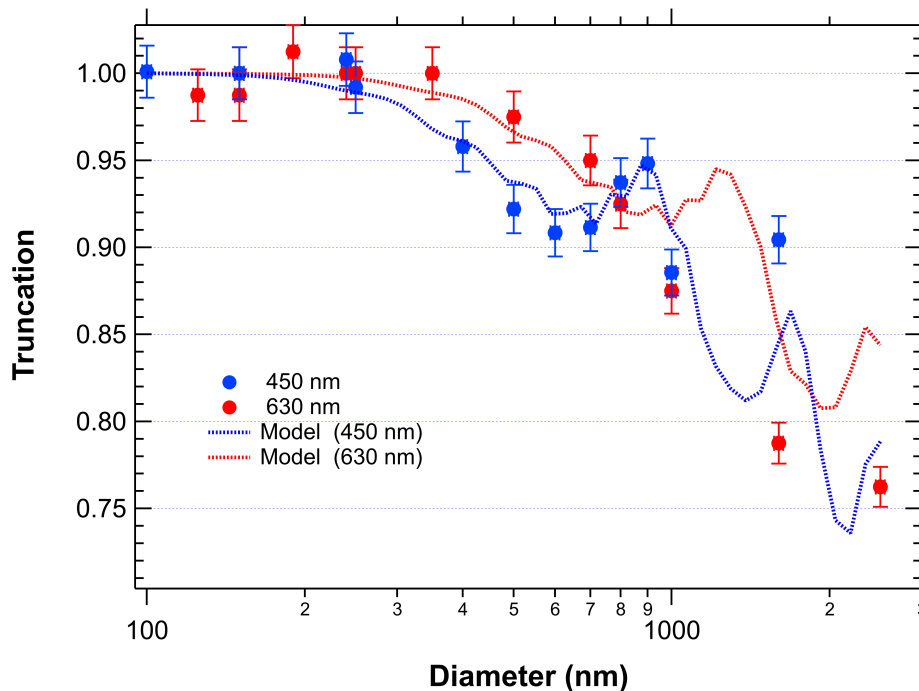


Fig. 5 Plot of measured truncation error as a function of PSL diameter for 450 nm (blue) and 630 nm (red). Also shown (dashed curves) are values calculated assuming Mie scattering and the geometry of the scattering cell.

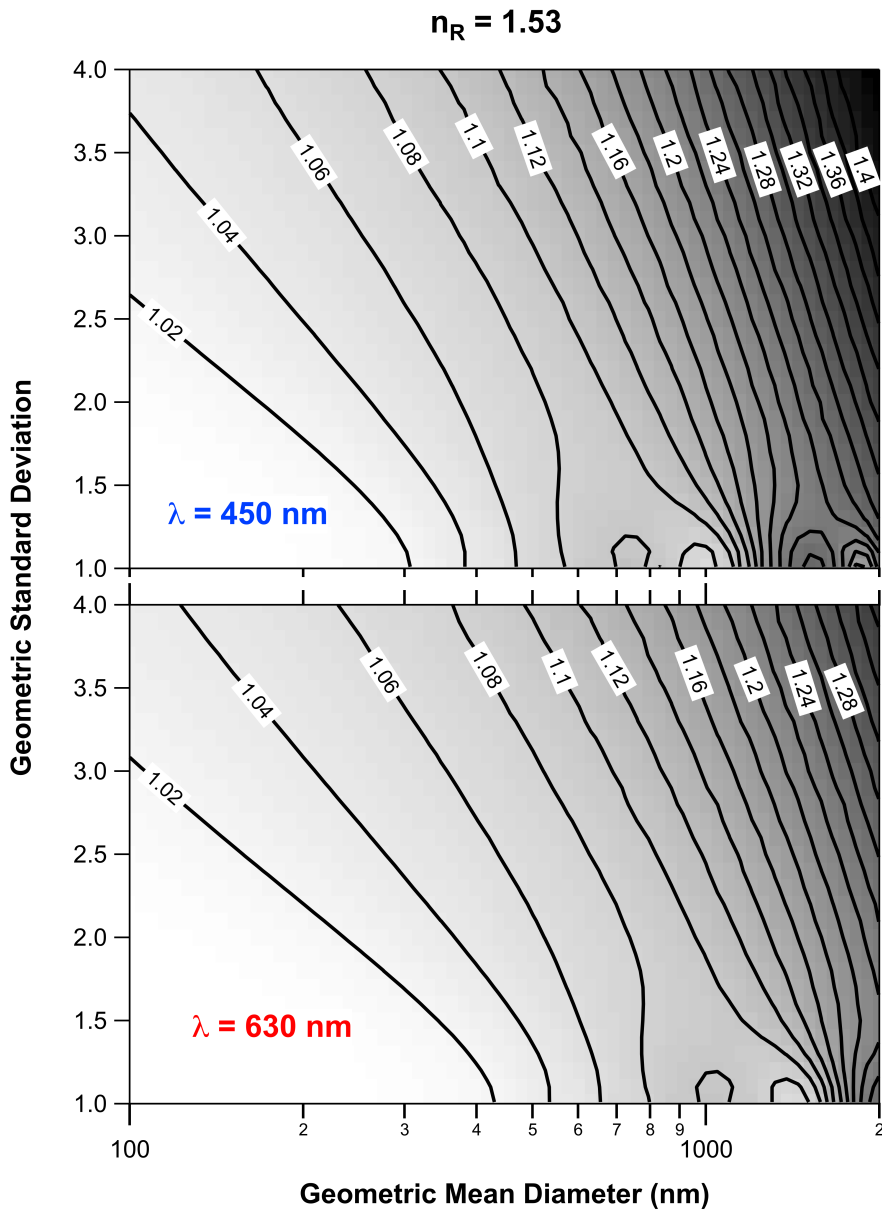


Fig. 6 Truncation correction calculated for polydisperse log-normal particle size distribution as a function of geometric mean diameter and standard deviation for both 450 nm and 630 nm.

## 6. DATA OUTPUT

The current extinction reading (with a 3 second time constant) is displayed on the front panel in units of  $Mm^{-1}$  (inverse megameters or  $10^6 m^{-1}$ ). At concentrations below 200  $Mm^{-1}$ , it will provide readings at a tenth of a  $Mm^{-1}$  resolution, but will revert to 1  $Mm^{-1}$  resolution at higher concentrations. It will not provide readings above 2000  $Mm^{-1}$ ; however, the digital output will continue to operate properly. The display unit is just a digital voltmeter which converts an analog 0-10 V signal generated by the computer to a digital reading. As such, it is prone to offset errors which limits its accuracy.

The true (and most accurate) readings are provided through the RS-232 connection located on the back panel of the monitor. The data is output as an ASCII file organized in the following order with:

1. Monitor Time – on-board clock (synched to computer at midnight)
2. Extinction ( $Mm^{-1}$ )
3. Scattering ( $Mm^{-1}$ )
4. Loss ( $Mm^{-1}$ )
5. Pressure (Torr)
6. Temperature (K)
7. Signal (arbitrary) – should be between 70,000 to 100,000 with no particles present
8. LossRef
9. Status - 5 digit number (see below)
10. WC
11. SigRef
12. RawScatRef
13. Rawscat
14. SDR
15. WCRref
16. Computer Time – Supplied by data acquisition computer (not present in output from monitor)

Items 8 and 10-15 are useful for diagnostics but otherwise are of no use to the casual user.

*Status* is a five digit number: abcde

*Status* is a five digit number: abcde

a) Pump and Filter (for units with internal scrubber units)

- = 0 Pump Off, No Filter
- = 1 Pump On, No Filter
- = 2 Pump Off, Filter In
- = 3 Pump On, Filter In

In normal operation, only 1 and 3 will appear in the status code

b) Baseline Status

- = 0 Normal Operation – No Baseline
- = 1 Baseline On- Flush Period
- = 2 Baseline On – Measurement Period

c) LED Status

- = 0 LED is On
- = 1 LED is Off (Used only for  $PM_{SSA}$  Monitor)



d) Monitor Type

- = 0 NO<sub>2</sub> monitor
- = 1 Gas phase absorption
- = 2 Aerosol Extinction
- = 3 Single Scattering Albedo Monitor
- =4 Multi-cell Monitor

e) Wavelength

- =3 Far Blue (405 nm)
- =4 Blue (450 nm)
- =5 Green (530 nm)
- =6 Red (630 nm)
- =7 Far Red (660 nm)
- =8 Near IR (780 nm)

The status number is typically used in subsequent data analysis to determine periods of baseline measurement or other upset conditions.

If the supplied monitor software is used to collect the data, a date and time marker which reflects the host computer date and time is automatically attached to the data as the last column, in addition to those listed above.

If the data are being collected with a user-supplied data acquisition program, it is recommended that all these data be recorded. They are required to reconstruct the data if there is a problem with baseline procedures, calibration, etc. and provide highly useful diagnostic information.

**We note that there is really just one temperature, pressure and status code which are repeated for each cell except that the wavelength of the particular cell is reflected in the status code.**

### On-Board Data Storage

The monitor automatically stores all data on a memory cache located in the computer stack that operates the monitor. It has the capacity to store approximately several years of data taken with a 1 second sample period. Once the memory is filled, it will begin to overwrite old data files.

In order to access the stored data by ethernet connection, use the ethernet port to connect the monitor either to a network or directly through your computer using a router. Use the supplied DAQ program to identify the IP address assigned to the monitor. Then use your browser with the IP address followed by a colon and 3000

IPaddress:3000

Click on the data folder. Clicking on any particular data file will cause the browser to download that file.

## 7. MAINTENANCE

### Particle Filter Replacement

The only regular maintenance required for the CAPS PM<sub>2.5</sub> monitor is periodic replacement of two filters used in the sample line. The replacement rate depends on the level of particle loading to which the monitor is exposed. Under normal ambient conditions, annual replacement could suffice. However, under high particle loadings (several hundred Mm<sup>-3</sup>) found when sampling combustion systems, for instance, the period could be a number of hours.

#### a. Inlet Flow Switching Valve

The first and most important is an in-line disposable (transparent blue plastic) filter which is used to remove particles for baseline measurements. This pressure drop across this filter can be measured by using the software command to turn off the pump and “open” the valve; the difference in pressure with and without the pump is essentially due to the presence of the filter. The pressure drop across this filter when new is a few Torr. Once the pressure drop in the filter reaches ~30 Torr, we recommend that the filter be replaced.

#### b. Outlet Filter

A disposable filter is used to remove all particulates before the sample flows through a critical orifice. This should be replaced periodically, especially when there is a noticeable color change or if the time response of the sensor increases.

Disposable Plastic Filter: DIF-BN60

available from United Filtration Systems (<http://www.unitedfiltration.com>).  
equivalent units available from Parker Balston and other suppliers

### Mirror Contamination

With proper operation of the monitor, the mirrors should never become substantially contaminated. However, this can occur because of a pressure upset or some other event. However, these monitors can operate within specification even if the mirrors become somewhat dirty. Contaminated mirrors cause a loss of signal and thus decrease in the sensitivity. However, this will not change the span value of the monitor. If the monitor noise increases substantially, one should check the measured optical loss (listed on the display and in the data files). Upon shipping, this value should be between 400 and 550 Mm<sup>-1</sup>; substantial loss of sensitivity probably would not be noticed until the loss approaches 800 Mm<sup>-1</sup>.

The mirrors are readily cleaned. Their coatings are relatively robust and should be treated just as one would treat any multi-layer optical film. Initially, gloves can be employed when handling the mirrors to avoid contamination. However, with practice, these are readily dispensed with.

#### *Required Supplies*

1. High quality lens tissue (we recommend ThorLabs)
2. Spectroscopic or HPLC-grade methanol and acetone
3. Clean **glass** bottles with **glass** eyedroppers
4. Supply of particle-free air or Aeroduster

5. A means of holding the 1" mirrors in place while cleaning – a plastic or Teflon block with a shallow wedge or cylinder with appropriate shoulder will work well. [CRD Optics sells inexpensive blocks suitable for this purpose. (<http://www.crd-optics.com/crd-blocks.html>)]

#### *Uncoupling of Detector Module from Sample Cell*

2. Use 7/16" nut driver to loosen clamp nearest sample cell on Detector Module.
3. Slide detector module off the cell and rest on floor of monitor.

#### *Removal of Cell from Monitor*

1. Disconnect the Swagelock fittings (i.e., a tee) attached to the sample cell.
2. Unplug connector on the wires coming out of the back of the cell from printed circuit board located on baseplate.
3. Unscrew the two (8-32) screws holding the cell onto the base plate.
4. Remove cell.

#### *Removal of Mirrors from Cell*

1. Starting at one end, unscrew optics holder, making sure to keep cell upright.
2. Remove o-ring from mirror using tweezers – o-ring might be attached to insides of optics holder. Do not misplace o-ring as it is required for proper operation of monitor.
3. Turn cell upside down and allow mirror to drop out of cell. Some tapping of cell might be required.
4. Repeat at second end to remove second mirror.

#### *Cleaning of Mirrors*

1. In a reasonably particle-free environment, place mirror on holding block with curved side of mirror up. The curved side will have a circular mark near the mirror edge.
2. Put the near edge of a single lens paper sheet on the mirror and allow 1-2 drops of solvent to fall on paper. (Do not overwet!! This is a beginner's mistake.)
3. When the mirror becomes fully wetted, draw the lens paper along mirror towards you. Repeat multiple times, first with acetone and then with methanol. With practice, one sheet of lens tissue can be used to make 3 different swipes. We recommend making at least 6 swipes with acetone and 6 with methanol.
4. Use dry air or emission from Aeroduster to remove any excess solvent.

#### *Replacement of Mirrors in Cell*

1. Place curved side of mirror into one end of cell, making sure that it is securely seated.
2. Replace o-ring on back surface of mirror.
3. Screw optics holders onto cell. They should be screwed on firmly but not overtightened – the aluminum threads can be damaged.
4. Repeat with other mirror.

#### *Putting the Cell Into the Monitor*

1. Slide the cell back into the plastic sleeve on the detector block. Be careful not to rotate the metal cylinder on the detector block.
2. Rebolt the sample cell to the baseplate using the two ¼-20 screws
3. Reattach Swagelocks to gas connections keeping alignment as before –  
**remember to attach the purge flow connection!**
4. Reattach the cables for power and output power and output to the PMT..
5. Reattach wires to power block taking care to **match the color of the wires** –black to black and red to red.

5. Put back cover with screws.
6. Reattach power cord and turn on monitor

*Note on mirror cleaning*

Learning to clean mirrors takes practice and patience. If you attempt to clean the mirrors and the results are worse than before or if they do not improve, just keep trying. Make sure that there is no lint or other particulate contamination on the mirror surface. A single visible particle is sufficient to cause substantial optical loss. Avoid performing this operation in high relative humidity environments as the evaporation of solvents can cause liquid water condensation on the mirrors.

**Cell Maintenance**

If the cell becomes contaminated, especially the purge area, remove the mirrors and clean them. Then, attempt to blow out the particles using a strong stream of dry air or a can of Aero-Duster. If this does not work, **do not attempt to take the cell apart**. If performance does not improve, return the unit to Aerodyne for servicing.

## 8. SOFTWARE COMMANDS

The following software commands are provided for those who want to control the monitor using their own software. Commands are entered as ASCII characters over the RS-232 connection. < > denotes a keystroke which is not a simple letter and \_ denotes a space. These commands can also be used using the supplied data acquisition software.

### General Information

All letter commands begin with <esc> and end with <cr> . (Note that <cr> here means 0x0D; <lf> (0x0A), if present, is ignored.) Some commands take 1 or 2 integer arguments, and where used, they are separated from the command, and from each other, by at least 1 space. While taking data, except for ?, these commands take effect at the conclusion of each observation. Thus, if data is being sampled at 10 seconds, it can take that long for the command to take effect.

### Commands active while taking data:

<i>Command</i>	<i>Argument</i>	<i>Function</i>
<esc>		Clear input buffer
<bs>		Delete Last Character
?		Ping; causes immediate return of ! character (0x21) in reply
B/b		Increase (Decrease) Pilot Light (front panel)1 step
F/f		Activate (Deactivate) Valve
P	{_0...4}	Select Front Panel Reading 0=Extinction (Mm <sup>-1</sup> ); 1=Pressure (Torr); 2= Temperature (K); 3 = Signal (mV), 4 = Flow (sccm)
Q		Leave Data Acquisition Mode and enter Interpreter Mode
V/v		Turn on (off) pump
X		Reply with "%DATA"
Z		Start Baseline Measurement Mode
z		Reset Baseline to 0

### Commands Active in Interpreter Mode (reached by typing {Esc}Q)

entered as {Esc}command \_ Argument1\_Argument2 (if required) where \_denotes space

<i>Command</i>	<i>Argument</i>	<i>Function</i>
<esc>		same as above
<bs>		" "
?		" "
A	none x_filename	start saving to default file save to filename
B/b		Increases / diminishes pilot light brightness
C		
D	mm/dd/yyyy	set date
E		Return Setup Table
F/f		Operate valves as in Run Time
G/g		Accept/Reject revised settings, return to measurements
H/h		Enable / disable Automatic Baselines
I		system status (integer divisors, mod and IF, actual integration time)
i		system status (autobaseline info, autosave info.)
J	sourcefilename_destinationfilename	transfers specified file to USB memory device – allows one to change file name for transfer NOTE: DOS terminology sourcefilename C:\Data\Sourcefilename destination file name D:\Destinationfilename IF USB DEVICE NOT PRESENT, SYSTEM WILL REBOOT IN 15 SECONDS
K	sourcefilename	transfers specified file over RS-232 port at enhanced baud rate -when file transfer is completed, baud rate automatically returned to 9600 baud
M	table number_value	modify setting (2 <sup>nd</sup> Esc return clears this command)
P		provides true zero to panel meter
p	newvalue	sets zero for panel meter

Q/q		Accept/reject settings return to Run Time
R		reboot monitor (same as alt-ctl-del)
S	command string	sends DOS commands to computer (e.g., del, dir) screen information returned
s	command string	sends DOS commands to computer (e.g., del, dir) no information returned
T	hh:mm:ss	Set monitor clock (24 hour time required)
V/v		Turn on/off pump
X		Reply with "%USER"

## 9. WRITING YOUR OWN DAQ

These are our recommended best practices for writing your own data acquisition system for an Aerodyne CAPS monitor. They are based on our own data acquisition system and are intended to aid in helping us to diagnose any potential problems that you may encounter with your CAPS monitor. Your CAPS monitor automatically begins emitting data over its RS-232 port and USB ports on startup. While this data stream is enough for normal operation, it is recommended that you also query and record configuration information about the internal state of the monitor whenever you connect to it. The information available includes:

- the version of the software installed on the monitor,
- its serial number,
- the type of monitor,
- the wavelength at which it operates, and
- configuration parameters and stored values.

The exact number and meaning of the configuration parameters depend on the type of monitor you own, but they will include information such as the time between baselines and the baseline flush and sample periods. You should consult the manual specific to your CAPS monitor for a full list of user configurable parameters.

In order to capture this information, you should send the following sequence of commands to the monitor over the RS-232 or USB connection. All responses from the monitor should begin with a percent sign as the first character.

Your CAPS user manual discusses the list of commands available for the monitor and the specifics of sending these commands over the serial line. As a reminder, you send one command per line, and they

- begin with hexadecimal code 0x1B
- are always ASCII characters
- the line ends with a carriage return/line feed pair 0x0D0x0A

COMMAND	RESPONSE	PURPOSE
X	% DATA or % USER	Determine the operating state of the monitor. In DATA mode, it emits measurements. In USER mode, it will stop emitting data and wait for user commands.
Q	% You are now in the command interpreter	If the monitor was in DATA mode, then this will switch the operating mode to USER. This command does NOT need to be sent if the monitor is already in USER mode.
I	% CAPS software © Aerodyne Research, Inc. % version: 0.9.28 % os: 3.10.17-1.0.0-technologic+g86f7675 ... % Exact Sample Time = .90	Requests information about the monitor. The response is a variable number of lines, but it will always end with last line shown. The most important information for support purposes are the second and third lines.



<b>E</b>	% 12 744 44 1 % 0742 17 5 10 % 60 3 5 3 % 180 195 160 400 % -83.98 77 27.60 100 % 1 0 1.250 1 % 1.250 559.72 0.100 -27.800 % 0.946 011 004 115006 % 125567 2 251 232522 % 585.323 3 81873 DHCP % 10.100.1.75 CAPS004 1 1	Returns the operating Environment (or parameter list) for the monitor. This is a variable length array of four white space separated values per line. For all current monitors, the third parameter of the first line contains the number of parameters in the list.
<b>D DD/MM/YY</b> <b>T HH:MM:SS</b>		Optionally set the current date and time on the monitor. When setting the date, you must also set the time, but they are sent as two commands on separate data lines.
<b>G</b>	% Starting CAPS Observations	Returns the monitor to DATA mode

You should follow this protocol and save the information before any data collection. This will ensure that you have a record of how the instrument was configured at the start of the sample run. Older instruments (the so-called “Gold” series) require that you exit DATA mode before you can request the monitor information (**I**) and operating environment (**E**) as well as most other commands. This means that you must determine the operating mode (**X**) before you can send a command. For backwards compatibility, we recommend that any customer developed data acquisition systems follow this practice.

Setting the date and time on the monitor is not required. However, data saved on the instrument is timestamped. Maintaining an accurate timestamp on this data has a significant impact on its usefulness. To avoid clock drift on the monitor, we recommend that you synchronize the date and time on the monitor to your data acquisition system daily.

**CAUTION** – Because the date and time are sent as two sequential commands, you may get unexpected results if you reset the clock exactly at or near midnight.

After sending the go command (**G**), the monitor will resume sending data over the RS-232 and USB ports.

Figure 5 shows the communications transactions on the serial port during the initialization procedure discussed in this article.

Figure 5 Recommended Initialization Sequence

